Title: Infrastructures and society: from a literature review to a conceptual framework

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Abstract

While economic and environmental aspects of civil engineering have attracted the greatest attention among contemporary academy, its social side has frequently been set aside. However, the social impact that infrastructures have is huge and its analysis and understanding are fundamental. At the same time, social aspects such as culture or human behaviour can have significant effects during the different stages of the lifecycle of infrastructures. Therefore, a better understanding of the connections between civil engineering and society can help to better adapt infrastructures to their contexts, as well as minimise their negative impacts; as a result, this understanding can bring about infrastructures that are more socially sustainable.

The scarce studies that have assessed the connection between society and civil engineering have considered this relationship as unidirectional. The real scenario is not so simple. The analysis of this relationship needs to be interdisciplinary, and it is in this context that this paper addresses the analysis of infrastructures and of social sciences from a sociotechnical point of view. We draw on the interrelationships found to propose a conceptual framework with the main objective of providing both practitioners and academics with tools to carry out more sustainable and context-adapted decisions. We classify the fields of civil engineering and social sciences into several different subfields, namely six for infrastructures (transport, water, energy, environment, urban planning and buildings) and twelve for social sciences (culture and history, behaviour and mind, communication and interaction, socioeconomics, juridical sciences, life and health, politics, social problems, social groups, ethics and philosophy, arts and education and innovation). Afterwards, we review the existing literature at the intersection between the various categories. We conclude proposing a framework that can support decisions and actions made at different levels and working areas. The framework includes guidelines for a more holistic consideration of the interaction between infrastructures and society in key activities whereby an improved understanding of the effect of this relationship is often required. The guidelines provide a description of different key areas and can be applied to a wide variety of actions ranging from the development of university curricula to the social impact assessment of projects.

1. Introduction

It is widely accepted that impacts from human activities are generally identified with three interdependent pillars: economy, environment and society. The first two pillars, economy and environment, have received considerable attention. However, when it comes to society, the research has been rather scarce (Taticchi et al., 2013 and Ahi and Searcy, 2015). According to Vallance 2011, it is the difficulty involved in the definition of this construct that has compromised the usefulness and importance of the concept. Even though it is clear that there is no agreement on the concept or the methodology that should be followed to assess it, it is generally acknowledged that social sustainability deals, to a greater or lesser extent, with social impacts.

Some variables that have been considered in the analysis of social impacts are health, safety, human rights and labour issues (Székely and Knirsch 2005, Kruse et al. 2009, Mani et al. 2014 and Popovic et al. 2018). In fact, more recent attention has even focused on the development of quantitative measures for the analysis of social impacts (Munier 2005, Ahi and Searcy 2015 and Taticchi et al. 2015). Additionally, there exist a number of approaches to evaluate social sustainability: the standards developed by the Global Reporting Initiative (Global Reporting Initiative 2015a, 2015b) on the one hand and the Social Life Cycle Analysis (SLCA) (Andrews et al. 2009 and Benoît-Norris et al. 2013) on the other. The first approach is oriented to business processes and includes some topic-specific standards that are to be used to report information on the social impacts of organisations. Some of these topics are occupational health and safety, training and education, public policy and customer privacy. Conversely, the SLCA draws from the assessment methodology developed in the context of environmental sustainability. Other approaches account for social sustainability as an integrated part together with economic and environmental factors. One example is MIVES (Integrated Value Model for Sustainability Assessment), which is a multi-criteria decision-making tool that allows to consider in a holistic way the different dimensions of a problem (Aguado et al. 2012 and de la Fuente et al. 2016) by structuring the framework into different levels, weighting each of the aspects and aggregating them. However, a consensus is yet to be reached on reliable indicators and methodologies that can be used for analysis.

It should be mentioned that, in general, the studies that have evaluated impacts from a holistic perspective, including those related to the social pillar, are more often found in specific areas such as business or supply chain management (see, for example, Carter and Rogers 2008, Hutchins and Sutherland 2008, Seuring and Müller 2008 and Pagell and Wu 2009). Most of these studies fail to consider many fields whose social impact is also important. It is the case, for instance, of civil engineering (CE), in which researchers have mainly devoted efforts to the analysis of economic and environmental sustainability of infrastructures (Martens and Carvalho 2016, Banihashemi et al. 2017 and Kivilä et al. 2017) but have neglected social sustainability. Few exceptions do exist, such as Sierra et al. 2017, Montalbán-Domingo et al. 2018 and Sierra et al. 2018.

However, the effects that infrastructure services such as the supply of water and electricity, the disposal and treatment of wastewater or the mobility of people and goods have on society is huge, since they are drivers for socioeconomic development, competitiveness and inclusive growth (Calderón and Servén 2014 and Serebrisky 2014). Infrastructures and the different stages existing from their initial planning until their decommissioning play a major role in sustainability, and in particular in social sustainability (Inter-American Development Bank 2018). At the same time, society poses constraints on the design, planning, construction, maintenance, operation and decommissioning of civil works. This means that the relationship between society and infrastructures is bidirectional as each one can affect the other in different ways.

Even though there is evidence on the fact that the analysis of the impacts of CE must be carried out from an interdisciplinary point of view, until the present, engineering and social sciences and humanities (SSH) have been set aside as separate scientific areas and research concerning the intersection between both of them has been very scarce. Decisions taken by engineers have, in very limited occasions, considered the participation or opinion of citizens and involved social groups, which are, actually, the ultimate users that would have to benefit from such decisions. The emergence of concepts such as socio-engineering indicates the growing relevance of connections between social and engineering/technological disciplines. Social studies of engineering have been showing the importance of understanding sociology when it comes to successful engineering. In the same way, technology and infrastructures are shaping the social world by enhancing, for instance, connectivity (both physical and digital) and comfort. As Bolton and Foxon 2015 point out, we need to understand better the interconnections between society and engineering in order to develop more sustainable and stable solutions.

It has to be born in mind that in many cases tools developed by engineers can be useful for the resolution of problems set out by sociologists, in the same way as approaches developed by professions of SSH can sometimes be applied in engineering fields. Besides, professionals are increasingly more aware of the indispensability of including citizen and social groups participation in the processes of decision-making, so that not only functional, economic and/or environmental factors are considered, but also social aspects.

Having said this, it is clear that interdisciplinary research on the analysis of the bidirectional relationship between SSH and CE is essential. In this context, the objectives of this paper are two-fold. On the one hand, it provides an overview of the social studies conducted in different areas of CE that allows proving the bidirectional relationship between the fields; on the other hand, it proposes a general framework that can be useful for both academicians and for practitioners.

This paper is organised as follows. The methodology that has been followed to review the publications concerning the relationship between SSH and CE is presented in section 2. In section 3, a description is given on the existing literature dealing with topics that fall in the intersection between the two fields. This literature is discussed in section 4, where also a detailed conceptual framework is also provided. Finally, section 5 outlines the conclusions of the study, together with its limitations and guidelines for possible future research.

2. Research process and method

The analysis presented in this paper has followed the systematic process that is shown in Figure 1, which schematically describes the different processes and subprocesses carried out. In order to analyse the social factors involved in the different stages of the lifecycle of infrastructures and to be able to establish a conceptual framework, the methodology followed has been a top-down approach. Since the main academic areas under study were CE and SSH, these fields have been broken down into their respective subfields in order to be able to describe in detail the specific relationships between CE and SSH.

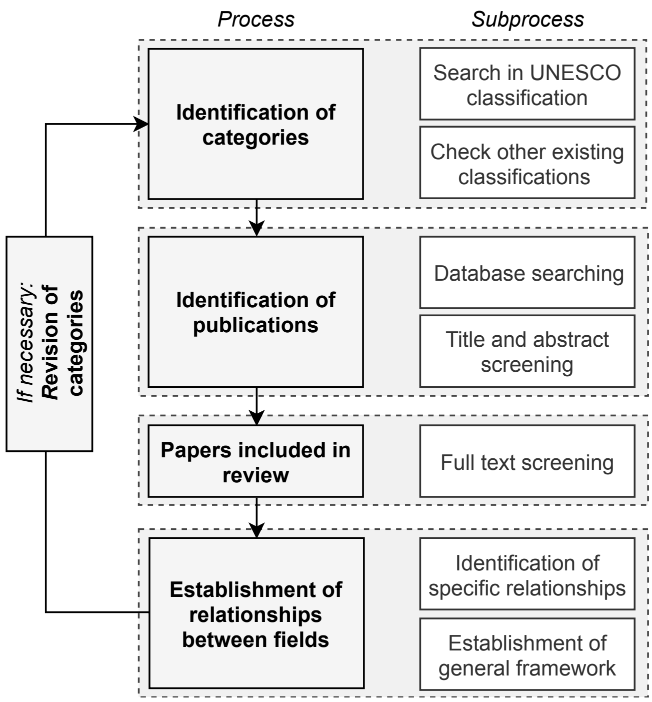

Figure 1 Research process followed

In order to perform a more effective review of these relationships, we have constructed a general classification scheme of the subfields within CE and SSH based on already existing categories. In the first place, the UNESCO nomenclature for fields of science and technology has been used. This nomenclature divides the scientific categories into fields (general sections), disciplines (speciality groups within the fields) and subdisciplines (most specific elements of the nomenclature). The fields that have been screened within the UNESCO nomenclature are “Earth and Space Sciences”, “Agricultural Sciences” and “Technological Sciences” (code numbers 25, 31 and 33 respectively) for CE and “Anthropology”, “Demographics”, “Economic Sciences”, “Geography”, “History, “Juridical Sciences and Law”, “Linguistics”, “Pedagogy”, “Political Science”, “Psychology”, “Science of Arts and Letters”, “Sociology”, “Ethics” and “Philosophy” (code numbers 51, 52, 53, 54, 55, 56, 57, 58, 59, 61, 62, 63, 71 and 72 respectively) for SSH. From these, the disciplines that were of interest for this paper’s study have been selected. Additionally, in order to check the exhaustiveness of the different groups of disciplines built, the classification made by international-level or regional-level professional associations have been checked. Namely, the American Society of Civil Engineers (ASCE) and the Institution of Civil Engineers (ICE) for the CE classification and the International Sociological Association (ISA) and the American Sociological Association (ASA) for the Sociology classification. As a result, on the one hand, the subdisciplines that have been established for CE are: transport, water technology, energy technology, environment technology, urban planning, buildings, natural hazards, construction management, construction technology and materials technology; nevertheless, the four last categories were considered to be already included in the previous categories and for this reason only the first six subdisciplines have been contemplated in the present paper. On the other hand, the subdisciplines established for SSH are: culture and history, behaviour and mind, communication and interaction, socioeconomics, juridical sciences, life and health, politics and policy making, social problems, social groups, ethics and philosophy, arts, education and innovation. Tables 1 and 2 show this classification, together with their taxonomy and their corresponding UNESCO codes.

This process has been implemented in two steps. First of all, papers relating the fields of CE and SSH in more general and theoretical terms have been searched. Secondly, publications regarding more specific topics (those within the subfields) have been searched. This was performed by searching in databases publications using the following protocol: (TITLE-ABS-KEY("CE keyword" AND "Social science keyword*") AND ALL ("civil engineering")). After identifying all the publications to be included in the review, we analysed whether the categories established were adequate or not, in which case they were to be modified and the database search done again.

Table 1 Taxonomy of each field of SSH and corresponding UNESCO's nomenclature codes

SSH dimension	*Keywords*	*UNESCO codes*
Culture and history	Culture, history, ethnics, religion, symbolism, tradition	5101, 5501, 5502, 5503, 5504, 5505, 5506, 5599, 5402, 6301
Behaviour and perception	Behaviour, mind, psychology, emotion, personality, social perception, anthropology, attitude, behavioural response, judgement	6101, 6102, 6103, 6014, 6105, 6106, 6107, 6108, 6109, 6110, 6111, 6112, 6113, 6114, 6199
Communication and interaction	Social communications, social interactions, participation, information provision	5701, 5702, 5703, 5704, 5705, 5799, 6308
Socioeconomics	Economics, economic activity, economic development, economic geography, socioeconomics, economics of technological change, industrial organisation, international economics, organisation and management of enterprises, sectorial economics	5301, 5302, 5303, 5304, 5305, 5306, 5307, 5308, 5309, 5310, 5311, 5312, 5399, 5401, 6306
Juridical sciences	Law, regulations, national law, legislation, tribunals, jurisprudence, international law	5601, 5602, 5603, 5604, 5605, 5699
Life and health	Quality of life, well-being, mental health, physical health, life course, safety, medicine, medical sociology	6306
Politics and policy making	Politics, policy making, resilience, governance, social policies, public administration, political institutions, policy sciences, international relations	5901, 5902, 5903, 5904, 5905, 5906, 5907, 5908, 5909, 5910, 5999
Social problems	Social development, poverty, inequality, social conflict, war and peace, social security, safety, crime, delinquency, disease, famine, globalisation	5103, 6304, 6307, 6310
Social groups	Social groups, tribes, women, children, youth, elder, casts, elites, family, social stratification, social classes, human geography, regional geography	5102, 5103, 5403, 5404, 6309, 6311
Ethics and philosophy	Ethics, social philosophy, moral, justice, classical ethics, ethics of individuals, group ethics, general philosophy	7101, 7102, 7103, 7104, 7199, 7201, 7202, 7203, 7204, 7205, 7206, 7207, 7208, 7299
Arts	Architecture, arts, visual appearance, aesthetics	6201, 6202, 6203, 6299
Education and innovation	Education, educational methods, training, pedagogy, innovation	5801, 5802, 5803, 5899

Table 2 Taxonomy of each field of CE and corresponding UNESCO's nomenclature codes

CE dimension	*Keywords*	*UNESCO codes*
Transport	Bridges, harbours, highways, waterways, railway, roads, tunnels, traffic, urban transit, railroad	3305, 3323, 3327, 3329
Water technology	Reclamation of water, sanitation, sewage and sewers, dams, drainage, irrigation, water purification and supply	3102, 3305, 3308
Energy technology	Power technology, power generation, power distribution, power transmission, unconventional sources of energy	3322
Environment technology	Air pollution control, industrial wastes, pollution engineering, radioactive waste disposal, refuse disposal, solid waste management, water pollution control	3308
Urban planning	Land use, regional development, urban environment, urban-rural relations, community organisation	3305, 3329
Buildings	Houses, industrial buildings, commercial buildings, public buildings, skyscrapers	3305

3. Results

In the following subsections, first of all, we analyse the reviewed publications by examining their distribution across time, as well as by seeing the fields that have been reviewed. Secondly, we describe the main points of the reviewed publications. The sections are classified according to the classification made for CE.

3.1. Analysis of the reviewed publications

After performing the database search as detailed in the previous section, more than 13000 references were found. The number of publications identified in this first stage is shown in Figure A.1. However, in spite of the large amount of literature that was found, from screening the title and the abstract in the end a total of 324 publications was reviewed. The difference between identified and reviewed publications is so significant mainly due to the existence of homonyms for some of the keywords used such as training, which can also be used in engineering in the field of artificial intelligence or such as building, which can also be used in other contexts besides CE. Of the selected publications, less than 1% belong to the period between 1970 and 1985, 17.3% were published between 1986 and 2005 and 82.1% between 2006 and 2019. Figure 2 presents the distribution of all the papers across time. It shows how the number of publications dealing with topics both from CE and SSH increased very quickly after the 80s. Besides, Figure 3 shows a colourmap that has been drawn based on the number of publications reviewed for each subfield and that also presents the percentages of publications that correspond to each of them.

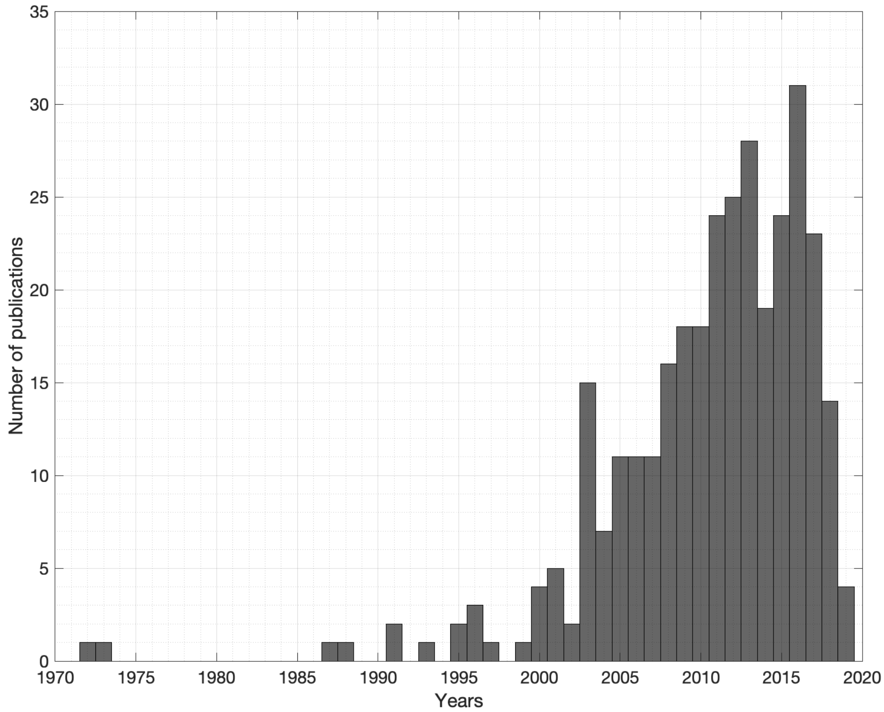

Figure 2 Distribution of publications reviewed per year

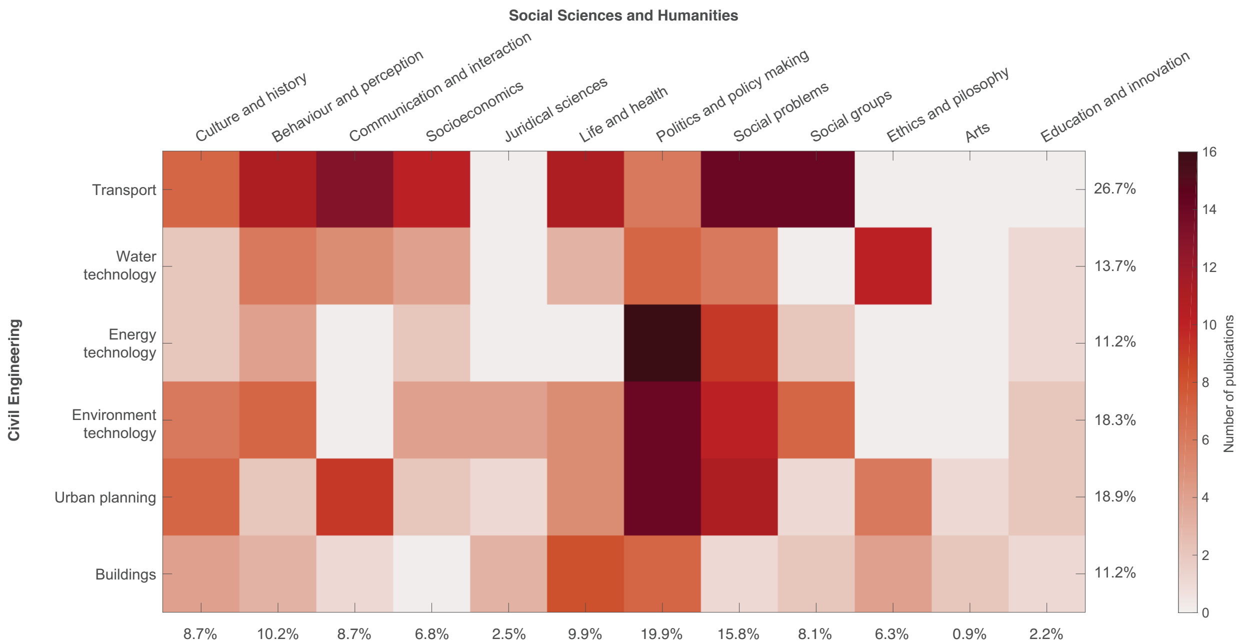

Figure 3 Number of publications that correspond to the different intersections between CE and SSH

3.2. Descriptive review

In the following sections, a synthesis of the reviewed publications is presented. Even though the objective of the paper is the analysis of the relationships between each of the subfields of CE and SSH, the findings have been described grouped according to their corresponding CE field for two main reasons: first of all, because of the large number of subsections that would be needed if there was one for each cell in the matrix of Figure 3; secondly, because some publications belong to more than one category in the social field.

3.2.1. Transport

Transport services and mobility infrastructures have always played an important role in the development of society (Ghimire 2017), originally through land- and maritime-based routes, but more recently also through air-based ones. Civil engineers working in transportation systems are responsible for the provision of safe, efficient and convenient movements of both people and goods.

The social study of transportation systems has given rise to a high amount of literature. For instance, Sheller and Urry 2006 describe how the development of both transportation infrastructure and modes has had a huge impact on the SSH and has transformed the relationship between travel and connections with social patterns and experiences. The cross-disciplinary research agenda drawn from these new relationships has been referred to as the “new mobilities” paradigm or the “mobility turn”; contributions to these paradigm changes come from several fields such as anthropology (Verstraete and Cresswell 2016), culture (Appadurai 1996 and Degen and Hetherington 2001), politics (Shiftan et al. 203) or geography and migration studies (Ralph and Staeheli 2011 and Kaufmann et al. 2004). Actually, there exists in the SSH a research area referred to as sociology of mobilities and space, whose study focus are the social aspects of movement. Although traditionally the study of mobility from a sociological standpoint has been that of vertical mobilities (Vannini 2010), or also called the social elevator, the mobility seen as a more material concept has been laid aside. Namely, mobility linked to the geographic movement of people for work and leisure or due to the need for migration within or between countries, for instance. Besides, some authors have argued that transportation is not merely the instrumental or neural tool for getting from A to B (Vannini 2010), but also an element that shapes relationships and interactions between people (Dugundji et al. 2011 and Pucci and Colleoni 2016), networks of time and space (Cresswell 2006, Grieco and McQuaid 2012 and Pathak et al. 2017) and provides meaningful different significances to experiences (Cresswell 2006).

The social approach to transport and mobility can be classified into a micro lens and a macro lens. The former approaches the relationship between SSH and transport by focusing on the individuals and firms regarding the use and provision of transport. The latter takes on a broader perspective by dealing with all the interactions caused by the transport network as a whole and at any level (local, national or international).

On the one hand, at the micro level, Jones and Lucas 2012 performed an extensive review on the social impact of transport and found that the main areas in which transport has influence are accessibility, movement and activities, health, finance and community relations. Church et al. 2000 classified this micro lens into two different categories: a category approach and a spatial approach. The former is concerned with factors related to transport demand (such as travel patterns, attitudes, needs, etc.) whereas the second approach comprehends aspects of transport supply like quality of transport, access (either to public or private transport) or spatial gaps.

Within the category focus, the analysis of the demand and its relationship with human characteristics is a field that has been given great importance. Many authors have been able to identify divergences in the usage of transportation which are usually directly correlated with differences in factors such as life course stage (Sun et al. 2009, Waygood et al. 2015 and McLaren 2016), gender (Grieco and McQuaid 2012 and Ghani et al. 2016), age (Collia et al. 2003, Hjorthol et al. 2010, Horner et al. 2015 and Ghani et al. 2016), culture or geography (van den Berg et al. 2017) and attitudes and behaviour patterns (Hackney and Marchal 2011). All these factors are, additionally, affected by individual subjectivities such as personality traits, attitudes and feelings (Murtagh et al. 2012, Bergantino et al. 2013, Heinen 2016 and Yazdanpanah and Hosseinlou 2016). These differences are not only in modal choice (transit, walking, cycling, carpools, etc.) but also in other aspects such as trip distances or purposes (Boschmann and Brady 2013). Additionally, apart from individual characteristics affecting demand, another aspect that has been studied is the effect of information provision on users (Emmerink et al. 1995). As Hackney and Marchal 2011 point out, all these factors do not appear independently at an individual level: there are interrelations between the transportation use that different people make.

Another central topic in mobility research is its intimate connection with well-being and quality of life (Doi et al. 2008, Spinney et al. 2009 and Delbosc 2012). Factors such as participation in activities outside of home, in social and community life or the communication and interaction with other individuals are directly related to social and emotional well-being (Schaie 2003, Mollenkopf et al. 2005, Vella-Brodrick 2013, Boniface et al. 2015 and van den Berg et al. 2017). Particularly, in this research field many authors have analysed the specific case of the elderly's accessibility and mobility (Musselwhite et al. 2015, O'Hern et al. 2015, Shergold et al. 2015 and Johnson et al. 2017); however, other studies have focused on other age groups such as teenagers (Ward et al. 2015). Webber et al. 2010 present a holistic framework that incorporates all the variables influencing the mobility of the elderly, such as their living situation and functional ability. Their framework includes different physical locations as well as five mobility determinants (financial, psychosocial, physical, environmental, and financial) that are influenced by gender, cultural and biographical characteristics. Spinney et al. 2009 emphasise the need for developing transport systems that account for their impacts on social exclusion and quality of life. In their work, they present an enhanced method to evaluate and critically understand the impact that transport mobility has on quality of life.

A particular case that has gained much attention is that in which these differences are occasioned on vulnerable groups or commonly excluded population. Actually, in the social studies of transportation, equity and social inclusion are some of the topics that have been more widely discussed (Lucas 2004, Currie et al. 2007, Geurs et al. 2009 and Delbosc 2012). The vulnerable groups may be constituted by children, women, older people, disabled people etc. (Wasfi et al. 2017). As some authors point out, incorporating policies dealing with transport-related inequalities into policies other targeting social inclusion objectives (such as residence or employment) can bring about better results on these objectives (Litman 2002 and Xia et al. 2016). The issue of social exclusion linked to transport relates to the concept of the right to mobility and of transport justice; this concept advocates for equal distributions of the benefits and burdens of urban transport (Gössling 2016 and Verlinghieri and Venturini 2017). Gössling 2016 identifies three areas in which transport injustices occur: exposure to traffic dangers and contaminants (Gaffron 2012), distribution of space and the value given to the time of transportation.

In order to be able to target problems stemming from social injustices in transportation, Hananel and Berechman 2016 built a decision-making framework based on Sen and Nussbaum capabilities approach (Nussbaum 2005). To this purpose, they analised the relationships existing between the different human capabilities and transportation theories. A difficulty encountered in this analytical methodology lies in the complexity of defining a valid threshold for real-life approaches to transportation. Other capability approaches to transportation that have been developed can be found in Wee 2012 and Wismadi et al. 2014.

As civil engineers, the different processes involved in transport infrastructures are carried out so that they are developed safely, efficiently and conveniently. Most frequently, the purely engineering side of transportation (such as construction requirements or service levels) conflicts with its societal side (Hananel and Berechman 2016). The main issues involved in this dissension are (1) the technical problems involved in the identification of disadvantaged populations and individuals; (2) the fact that, in general, transportation models are based on the average trip-maker or resident and therefore the planning measures and design are carried out accordingly; (3) economic and political feasibility.

On the other hand, moving to its analysis from a macro perspective, transport has been seen as a catalyser of economy for various reasons: an improvement in the efficiency of transport systems can generate productivity gains and therefore, produce an economic impact; at the same time, enhancing people and industry's access to certain resources, services and markets can also improve productivity. Other noticed impacts are the support of clusters and agglomerations, the enhancement of access to jobs and labour market and the opening or enlargement of markets for businesses (Jiwattanakulpaisarn et al. 2010, Arbués et al. 2015, Holl 2016, Litman 2017 and Meersman and Nazemzadeh 2017). Not only does transport infrastructure impact the region in which it is located, but it has the potential to reach nearby regions through what is known as the spillover effects (Holtz-Eakin and Scwartz 1995, Jiwattanakulpaisarn et al. 2012 and Yu et al. 2013). Apart from considering the economic effects that transportation systems have on society, transport engineers must also take into account other conditions that might restrict their design and planning processes, as well as affect their performance in the long-term: geographic constraints and political interests (Carpintero and Siemiatycki 2016).

3.2.2. Water technology

Water is essential for life and human beings need a minimum amount of water to survive; therefore, infrastructure providing water is fundamental (Koo and Ariaratnam 2008). This importance was acknowledged long ago; the right to water and sanitation services was included in the list of universal human rights by the United Nations (United Nations Development Programme 2010), and Lorrain and Poupeau 2014 referred to water supply services as an essential piece within human settlements due to their socio-technical nature. The impact that water technology has on societies is huge; apart from the benefits obtained from it such as covering the basic physiological needs and other dimensions of human well-being, it can also have serious consequences such as the dislocation of whole communities (Nüsser 2003). Brauman et al. 2007 proposed connections between different hydrologic systems and human well-being; the dimensions that they considered were basic needs, physical and emotional health, social interactions, security and freedom.

Water provision is multidimensionally affected by technical, economic, environmental, social and political factors. Even though traditionally the management of water resources has been mainly based on technical solutions and its infrastructure planning processes have been highly influenced by engineers and local authorities, this is starting to shift towards a more society-oriented focus. This means for instance to involve SSH research (Lienert et al. 2013), to allow for governance and cultural adaptation, to adapt to new challenges such as changing socio-economic conditions and uncertainties due to climate change (Pahl-Wostl et al. 2007) or to involve the values of individuals and stakeholders in the decisions concerning water management (Lennox et al. 2011).

Actually, water infrastructure planning processes involve a complex network of stakeholders. At the same time, infrastructures themselves, such as of water supply or watershed affect numerous actors (Ison et al. 2007). Lienert et al. 2013 group the stakeholders that play a role in water infrastructure planning according to the level in which they make the decisions: local, cantonal or national. Within the local level, actors such as local engineers, planning consultants, suppliers, municipal administration and politicians and manufacturers can be found; within the cantonal one, cantonal agencies, offices and councils; within the national one, country associations, federal offices or NGOs.

As pointed out by Lennox et al. 2011, the engagement of stakeholders in decision-making is of importance in the governance of water resources. Examples of studies of social participation methods and case studies can be found in Hartley 2006, Ison 2007 and Pahl-Wostl et al. 2007.

The term governance used as a core theme in the global water discourse rose around the beginning of the 21st century (Mollinga 2008) and this allowed for the consideration of more aspects apart from the operation of water infrastructures itself, such as interest groups or social participation. This term embraced a more inclusive concept in contraposition to words such as government or management. As Rogers et al. 2003 introduce, governance encompasses the connection society-government since it is the collection of systems, political, social, economic and administrative, whose aim is the regulation and development of water resources management and provisions of water services at different levels of society. Some key aspects of good water governance are ethicality in the decision-making processes, impartiality by the decision-maker and inclusion of all the relevant actors (Lukasiewicz et al. 2013a, 2013b, Neal et al. 2014 and Syme et al. 2015).

Water-related problems have frequently been related to problems of justice and therefore governance of hydrologic systems needs to consider the justice implications of their activities. The fair distribution of water access and political water decision-making has attracted attention since it affects the water rights and water-based livelihoods of many communities around the world (Zwarteveen and Boelens 2014) and has caused conflicts and social movements (Davidson-Harden et al. 2007 and Neal et al. 2014). Further studies on water distribution and water injustices can be found in Budds 2004, Loftus 2009, Ahlers 2010 and Perreault et al. 2012 and on the centralisation of water resources in Gandy 2003 and Swyngedouw and Heynen 2003. These issues have often led to spatial inequalities (Harvey 1973, Nilsson 2006 and Kudva 2009). Related to these are the existing gaps and unequal distribution of the supply of water and sanitation services. In metropolitan areas, for example, water scarcity is becoming a problem due to the gap between the rapidly increasing demand and the infrastructures supply capacity (Britto et al. 2018), infrastructures that are poorly maintained and irregularities in the supply. For an extensive review of contributions related to water justice, the reader is referred to Neal et al. 2014.

In the design of hydrologic systems, an additional social aspect that needs to be included is human behaviour and attitudes towards water use and demand; this is not the result of a single variable but of a variety of different factors such as household size, income or available infrastructure (Sofoulis 2005, Braden et al. 2009 and Ahmadvand et al. 2011). This fact leads to differences in water consumption among different social groups. Additionally, there are other external factors that also influence this behaviour, such as social pressures or the influence of different lifestyles (Kitamura et al. 1997). There have been alternative studies concerning water consumption behaviour, in this case in how individuals conserve this asset (Thompson and

Stoutemyer 1991, van Vugt 2001, Lehman and Gellar 2004 and Wolfe 2009). Also, how communication concerning water-related issues is carried out might influence these attitudes towards it (Johnson 2008).

3.2.3. Energy technology

Energy has historically had a crucial role in social development. Even though energy systems have traditionally been seen as technological and economic phenomena, they are actually strongly connected to several social, political and organisational factors (Miller et al. 2015). This emphasises the importance of analysing energy from a social point of view. Actually, according to Strauss et al. 2013, the challenges that power technologies currently face are social rather than technological; along this line, Hornborg 2013 specifies the multiple perspectives that energy takes: historical, sociological, economical, ecological, cultural, epistemological, etc.

The social studies on energy in the literature mainly focus on three different areas: its political, ethical and socioeconomic implications (which are mainly related to energy governance and justice), the factors that influence the use and demand of energy and the attitudes towards and perceptions of energy.

Access to energy is one of the sustainable development goals and it advocates for energy services that are affordable, reliable and modern for all population. Therefore, energy policies and priorities need to change together with this paradigm shift. At the core of the change needed lies energy governance, understood as the way in which actors establish and enforce rules to address energy-related problems has extensively been treated in the literature. Many researchers have presented the challenges related to effective governance existing such as unclear levels of resilience and authority, weak resilience, inadequate prioritisation of investments or political conflicts (Goldthau and Sovacool 2012, Poocharoen and Sovacool 2012, Stokes 2013, Langlois-Bertrand et al. 2015, Bolton and Foxon 2015 and Sequeira and Santos 2018), as well as described governing arrangements and norms that would allow to approach these challenges (Delina 2012). Besides, energy governance has been considered at different political levels and even though it has mainly been looked only at local or regional (Peters et al. 2010 and Parag et al. 2013) and national levels (Sovacool and Mukherjee 2011), some authors have advocated adopting a global perspective on energy governance since, they argue, energy is a global public good (Gururaja 2003, Benner et al. 2010, Karlsson-Vinkhuyzen et al. 2012 and Bruce 2013). International energy markets have often been seen as lacking appropriate governance due to the ineffectiveness of governments and non-State actors in global coordination and regulation of energy services (Florini and Sovacool 2009). According to Fontaine 2011, energy governance usually follows two different patterns: a hierarchical one, which is centralised and state-centred; and a cooperative one, which is more decentralised and market-oriented. Following this line, Williams 2010 and Goldthau and Sovacool 2012 study the (de)centralisation of energy.

Giving a perspective that focuses more on the energy infrastructure itself rather than on the necessary political structure, Bolton and Foxon 2015 describe the collection of governance challenges that can be encountered during the different stages of the lifecycle of infrastructures. They also analyse the importance that certain actors play, such as government, private network operators, local authorities and energy regulators. Along with this line, Parag et al. 2013 specifically assess the incorporation of certain actors in energy governance networks.

Apart from energy governance, another concept that is frequently mentioned in social analyses of energy is energy justice. This refers to the global energy system that distributes in a fair way the benefits and burdens of energy services and that contributes to more representative and inclusive energy decision-making (Sovacool et al. 2017). Regarding energy justice, two main issues arise: energy poverty and energy inequalities.

Firstly, as for energy poverty (also referred to as fuel poverty, domestic energy deprivation or energy precariousness), there is not yet a common agreement on its definition. Some have defined it as a household's lack of access to socially and materially needed levels of energy services (Bouzarovski 2014), while others have referred to it as the lack of access to affordable and high-quality energy services (Bazilian et al. 2014). In spite of the differences in definition, what has been made clear is that energy poverty is a multidimensional problem shaped by several different circumstances apart from its technical performance. Some important drivers of energy poverty are the socio-economic situation of the household, the efficiency of the energy system of the dwelling and energy prices (Boardman 2013 and Meyer et al. 2018). At the same time, vulnerability to energy poverty is dependent on different factors, both at a household level such as income, age, or dwelling typology (Bouzarovski and Simcock 2017) or at external levels such as the high cost of energy. The measurement of energy poverty has faced various challenges for diverse reasons such as that energy is a private service, that it is spatially and temporally dynamic or that its quantitative evaluation might be subjective. Accordingly, the methodologies proposed differ widely. Some of them are the expenditure-based measurement, which uses the 10% rule (Boardman 1991), the Minimum Income Standard approach (MIS) (Bradshaw et al. 2008) or the Low Income High Cost (LIHC) indicator (Hills 2011).

Secondly, studies on energy inequality can be found in references such as Yenneti et al. 2016 and Bouzarovski and Simcock 2017. As pointed out in their paper, the amount of research performed on this topic is still scarce and it actually focuses on commonly studied groups such as elderly people and people living in rural regions; urban dwellers and collectives such as immigrants and tenants have not received as much attention (Bouzarovski 2014).

In the design of energy systems, prediction of energy demand is essential. Therefore, it has to be considered in the design and construction stages of energy infrastructure. Factors influencing energy consumption are not only technical but also related to the context. As pointed out by Zhao and Magoulès 2012, these factors include: climatic conditions, characteristics related to the building such as its area or orientation, characteristics related to the user, building services systems and operation, behaviour and activities of the users, social and economic factors such as level of education and energy cost and the indoor environmental quality required. The papers in the literature that are related to the modelling of energy consumption behaviour are numerous (Allcott 2011 and Yu et al. 2011).

According to many authors, how energy is developed, used and contested is shaped by how individuals and collectives conceive it. For instance, Strauss et al. 2013 describe the bidirectional relationship between cultural concepts and beliefs with energy: how individuals perceive energy transforms how they make use of it; at the same time, different uses of energy also modify individuals' beliefs about energy.

3.2.4. Environment technology

Environmental quality has a strong influence on the quality of life of human beings (Banzhaf et al. 2014 and Domínguez-Gómez 2016). Besides, the roles that civil engineers play within environment technology, which are related to the connection between human action and engineering principles and environment, are fundamental. They undertake the task of protecting humans from the effects of environmental actions and the enhancement of environmental quality. Mainly, they work on recycling, water pollution, air pollution and solid waste management (SWM) and resource recovery systems. Even though SWM has been considered by some as one of the most important challenges for a sustainable design of cities (Sharholy et al. 2008, Shekdar 2009, Zaman and Lehmann 2011 and Guerrero et al. 2013), systems for SWM have not received as much attention as sectors such as the water or energy ones. Due to the rapid increase in the number of city dwellers around the world, there has been an acceleration of solid waste generation rates. In this context, engineers need to provide inhabitants with SWM systems which are both effective and efficient.

The social dimensions that need to be considered when designing such a system are multiple. Actually, some authors have advocated for integrated systems (Integrated sustainable solid waste management systems) in order to be able to encompass all the complexities and multidimensionality of these systems (Pahl-Wostl et al. 2007, Shekdar 2009, Guerrero et al. 2013 and Marshall and Farahbakhsh 2013). The performance of these environmental technology systems depends strongly on human attitudes and collective behaviours. Also, socioeconomic, demographic and cultural factors have been pointed out as critical when it comes to understanding the barriers to the adoption of these technologies and new management strategies. Such factors include, among others, age, gender, income, education, family size, residence type, location, cultural beliefs and the historical context (Bandara et al. 2007, Pahl-Wostl et al. 2007, Marshall and Farahbakhsh 2013, Ma and Hipel 2016, Gallego-Álvarez and Ortas 2017 and Kopnina 2017). The wide variety of variables on which the performance of environmental systems depends emphasises the need for adapting these systems to the socioeconomic, demographic and cultural contexts. Also, policies and decision-making processes on environmental technologies need also to consider the huge effect that these infrastructures have on people's health and quality of life (Pacione 2003 and van Kamp et al. 2003).

Governance also plays an important role in these processes. For instance, it can help to integrate effective user participation or feedback learning (Berkes 2010). Therefore, good governance should aim at incorporating the numerous stakeholders involved and interested in waste management: national and local governments, municipal authorities, city corporations, non-governmental organisations, households, private contractors, ministries, recycling companies, etc. (Srivastava et al. 2005, Yedla 2012, Lederer et al. 2015 and Joseph 2006). Yedla 2012 suggests that stakeholders join into partnerships, which not only would bring economic benefits but also systemic ones. Policies concerning the involvement of these stakeholders in the process of waste management and the various stages of SWM have been developed (Taylor 2000 and Ma and Hipel 2016). These policies include laws and regulations such as bans, control standards or product specifications (Zhang et al. 2010, Moh and Abd Manaf 2017 and Vassanadumrongdee and Kittipongvises 2018); they also involve incentives that are socio-psychological or economic such as public subsidies, user charges or product charges (Troschinetz and Mihelcic 2009, Chen et al. 2010 and Lohri et al. 2014).

According to Awuorh-Hayangah and Oladapo 2015, good governance and sustainability in environmental management are intimately linked to justice, corruption-free, non-partisan and stable political systems. Among these, justice, and more specifically distributive justice, is a central theme (Chaix et al. 2006, Fan 2006, Hillman 2006, Pearce et al. 2006, Myers 2008, Patel 2009, Higginbotham et al. 2010, Walker 2012 and Kubanza and Simatele 2016). In particular, there exists an ongoing discussion about the low social status that is associated to one of these stakeholders, waste workers, as well as about the existence of an informal sector that has emerged from solid waste. This informal sector is made up of unregistered, unregulated individuals, groups or small businesses that benefit from waste (Nzeadibe and Anyadike 2012). These individuals are potentially under labour intensive situations and working at low income rates. The existence of this informal sector is directly related to socio-economic conditions, to policies related to urban environmental management and to the physical characteristics of urban regions. All these factors increase the availability of waste for the informal sector (Sembiring and Nitivattananon 2010). In some countries, the amount of people working a living from waste is large, which brings about more poverty and marginalisation (Berthier 2003).

However, vulnerabilities are not only related to informal sector workers. In all the stages of solid waste treatment (collection, transport, storage, classification, clearance, sell, reuse) environmental contamination may cause a differential impact on the exposed populations in terms of health, income and access to services. The same happens with air and water pollutants. This impact is potentially greater on vulnerable groups or communities such as children, women, elderly people, poor people or minorities (Makri and Stilianakis 2008, Candela et al. 2013, Nunn and Gutberlet 2013, Giovannini et al. 2014 and Levy and Patz 2015).

Finally, apart from environmental justice, some authors have also considered the importance of resilience and adaptability in the discourse of governance of environmental systems (Sandoval et al. 2014 and Popke et al. 2016).

3.2.5. Urban planning

Urban planning is the discipline that is in charge of several aspects of the planning, design and development of land use and built environments of municipalities and communities. It is a field that was traditionally formalised by architects and civil engineers; however, since the last decades this has changed and urban planning has permeated into other areas such as economic development or environment. According to Schmidt 2008 and Schmidt and Németh 2010, public space is not only a physical space but also a dynamic construct created by society that is influenced by politics, culture and factors related to public health. This shows how the connections between the tasks that urban planners perform are strongly linked to those of social scientists. Actually, Pickett et al. 2004 recognize cities as a whole, both ecologically and socially, and advocate for forming teams of interdisciplinary professionals who can provide better designs by creating urban models that are socially and ecologically sensitive. Besides, urban spaces are continually evolving, their form and functions adapting to the different social, political and economic circumstances. Recent political and economic transformations, such as globalisation, increased mobility and the boost of telecommunications technology have brought with them changes in the ways cities and public space are produced (Logan and Molotch 1987 and Schmidt and Németh 2010).

As for the concept of public space *per se*, it is not easy to find a unique definition. The way public space is perceived depends on anthropological and cultural dimensions such as class origins or ethnicity and there can actually be big differences between the perceptions of planners and users (Oliver-Smith and Goldman 1988). Jamalinezhad et al. 2012, for instance, recognise the effect of culture as central in urban planning, apart from political, economic and social factors (Jamalinezhad et al. 2012). This is, in part, due to the fact that built human settlements (such as cities or residential area compounds) comprise important tangible manifestations of human culture. Examples of studies focused on the way urban development and form change according to cultural factors can be found in Larson 2003. Chadha and Onkar 2016. Blessi et al. 2016 provide a description of the role of culture in contemporary urban life. As pointed out by the author, culture can have substantial impacts on urban areas by providing them with meaningful symbolic, competitive, environmental, economic and social value. Additionally, urban forms contribute to the aesthetics of the public space (Garrett 2016).

There are many papers in the literature that are related to how different forms of urbanism can have several different effects on individual's and communities' health and quality of life. There is a strong connection between various urban features and physical and mental health (de Hollander and Staatsen 2003, Díez et al. 2016 and Dong and Qin 2017) or quality of life and human wellbeing in general (Pacione 2003 and Khalil 2012). Of these features that influence individual wellbeing, the following ones can be emphasised: green spaces, urban density (Guite et al. 2006), commuting (Stutzer and Frey 2004) and housing (Albouy 2012). Furthermore, physical environment not only has an individual impact, such as on human well-being, but it also has collective effects on communities: it affects the way people behave and interact (Shin 2009 and Glanz 2016). Urban forms create opportunities for social interactions (Huang 2006, Shin 2009, Farida 2013 and Leikkilä et al. 2013) or can even control or create barriers through, for example, urban planning laws and regulations, which arrange the social relations between and within social groups by regulating the places for social gatherings (Shin 2009).

Urban governance, planning for resilience and urban justice are three topics that have widely been discussed in the literature. Currently, the models of urban governance around the world are numerous, since its organisation depend on local and national contexts that are intimately linked to general norms, values and practices (Pierre 2011). Da Cruz et al. 2019 carry out an extensive review on currently discussed challenges among academic publications. Their results show that the five topics that attract more attention are citizen participation, institutional shortcomings, government capability, civil society organisation engagement with decision making and vertical coordination between government tiers. However, they argue that there is a disconnection between what academics are concerned with and the reality in cities around the world. Through a survey, they present the challenges that are currently being faced by cities; the first five ones are insufficient public budgets, the politicisation of local issues, the interdependence of policy issues, inflexibility in the bureaucratic procedures and rigidity of rules, and lack of municipal autonomy. Some challenges that have been identified in relation to urban governance and resilience are globalisation, climate change, migration and security (Brenner 1999, Pelling 2010, Evans 2011 and da Cruz et al. 2019).

Finally, urban justice is generally understood as the right to a safe living environment and access to urban resources. Examples of studies on theories of justice related to urbanism can be found in Fraser 2009, Attoh 2011, Walker 2012, Nygren 2013, Schlosberg 2013 and Wayessa and Nygren 2016. Aspects that need to be accounted for in urban planning are accessibility (De Montis and Reggiani 2013). From a more practical standpoint, the right to the city has been studied in Merrifield 2014 and de Vries 2016. Nygren 2018 deals with both justice and governance problems. Tonkiss 2013 also points out that planning and designing urban environments is a "social process". As pointed out by Harvey 2003, city justice is not only related to having access to urban resources, but also to being able to participate in the changes to which cities are subject; this shows how, for some, participation needs to play a central role in urban planning. Participation, which is disjunctively seen as involving people in the making and implementation of policies and as including people in government structures, has been dealt in relation with urban planning by several authors (Hassan et al. 2011 and Wissen Hayek et al. 2016). Accounting for citizens in the design process of urban landscapes is important to promote community support and to bring about better urban configurations (Matsuoka and Kaplan 2008). Another benefit of increasing participation is, as Hassan et al. 2011 point out, the prevention of social exclusion. If practitioners don't consider the characteristics and needs of all citizens, benefits and burdens among human populations might be socio-spatially distributed; this means that it is possible that some people and places are devalued in comparison to others (Nygren 2018). For example, Gerometta et al.

2005 present a case in which city dwellers suffer most from social exclusion and urban policies potentially result in institutions that are more exclusionary. Other studies of inequality related to urban planning can be found in Manley 1996, Barbosa et al. 2007, Dai 2011 and Shanahan et al. 2014.

3.2.6. Buildings

The spectrum of social topics concerning buildings is wide. In this review, we have identified four main areas related to this field: social housing, health and comfort, social perception of liveable spaces and construction management.

First of all, social housing, whose aim is to provide liveable spaces that are more affordable, has been considered key in social policies (Bramley 2007); some analyses of its plan, design and impact on users can be found in McManus et al. 2010, Kowaltowski and Granja 2011, Sunikka-Blank et al. 2012, Yao 2012, Sdei et al. 2015, Salzer et al. 2016 and Morano and Tajani 2017, which mainly approach the improvement of energy efficiency and sustainability of this kind of buildings.

Secondly, many publications deal with the impact on people's health of buildings and comfort from different perspectives. As for health and quality of life, research has mainly focused on liveable conditions for the elderly (Leung et al. 2016, 2017). As for comfort, this entails aspects such as temperature (Fanger 1970 and Alfano et al. 2014), perception of vibration (Kwok 2009), acoustics (Beranek 1957 and Harris and Shade 1994), olfaction and aesthetics (Veitch 2001 and Alfano et al. 2014). Some authors have referred to this collection of factors as indoor environmental quality (IEQ). In relation to social housing, some authors have analysed how sometimes residents of these buildings are more prone to reporting discomfort (Vakalis et al. 2019).

Thirdly, how housing and buildings in general are perceived by their users and society is described in the literature. These publications deal with diverse aspects such as social response to construction delays (Hussain et al. 2017), perception of risk (Khew et al. 2015) and the way buildings change how places are experienced (Hadi et al. 2018).

Fourthly, construction management is the service that provides the techniques to manage the different stages in the life cycle of an infrastructure (planning, design, building, operation, maintenance and decommission); therefore, of the factors that have been mentioned in this paper dealing with the different CE subfields are implicitly embodied in the process of construction managing. Here we focus on publications dealing with the inclusion of social aspects in construction projects in general terms/itself. The great majority of reviewed papers dealt with the incorporation of social elements as part of the process of considering sustainability in construction projects. Many authors have emphasized the lack of integration between social issues and construction project management (Choguill 1996 and Marcelino-Sádaba et al. 2015). Some of the barriers to better social assimilation in projects are the complexity of the systems (Ravetz 2000), the lack of social awareness (Tan et al. 2011), lack of support from project stakeholders (Morrissey et al. 2012) or laws and regulations. As for this last impediment, even though there exist laws and regulations that are socially beneficial (Gan et al. 2015), they can sometimes be detrimental for society (Zhang and Dong 2011, Zhang et al. 2012 and Gan et al. 2015). As pointed out in Morrissey et al. 2012, early intervening in infrastructure projects to account for social aspects is potentially more effective and efficient when it comes both to economic and social terms; to support their viewpoint, they propose a framework for the development of infrastructure at different strategic levels. Corporate Social Responsibility has also been highlighted by some authors in order to induce ethical behaviours which could lead to a wider acknowledgement of the social dimension of construction projects (Hutchins and Sutherland 2008 and Shen et al. 2010).

Finally, other research topics found include the relationships between stakeholders and the ethics underlying them (Vee and Skitmore 2003 and Moodley et al. 2008), resilience and sustainability (Zhang et al. 2011 and Bocchini et al. 2014), the adequacy of buildings to context's characteristics such as tradition (Kaklauskas et al. 2005 and Braz et al. 2011), factors affecting construction delays (Subramani et al. 2016) the importance and benefits for communities of built heritage and its conservation (Tweed and Sutherland 2007 and Nesticò et al. 2018) and informal settlements (Caballero Moreno et al. 2019).

4. Discussion

The results of the literature review show that there exists a large amount of literature on topics concerning the intersection between infrastructures and social topics. Every subfield of CE and of SSH is related to each other dually, heterogeneously and dynamically. The dualism comes from the fact that infrastructures shape and are also shaped by society. The heterogeneity stems from the fact that certain connections are stronger than others. Finally, the relationship is dynamic because it changes under different circumstances. Actually, from the reviewed literature it is possible to observe that for a specific relationship between one type of infrastructure and a social dimension, the kind of effect produced will be defined by three main variables. These variables are referred to as externalities and are the following ones:

- Stakeholder: the effects that are produced as a consequence of the interaction between CE and the different SSH domains depend to a great extent on the stakeholder that is considered (user, engineer, local community, society, value chain actors, etc.).
- Time: the type of impact produced depends on the stage of time of the infrastructure considered. In general, we can assume that the existing general stages in the lifecycle of infrastructures are: planning and design, construction, operation and maintenance and decommissioning.
- Others: finally, apart from the factors related directly to CE and SSH, and from the ones concerning the lifecycle and the stakeholder, other aspects can also influence the kind of relationship between SSH and infrastructures. Examples of these aspects are natural hazards or different geographic locations.

Hence, the relationship between the two scientific fields can be described three-dimensionally. While the matrix that would represent all the intersections between subfields of CE and subfields of SSH is two-dimensional, all these intersections are at the same time characterised by the three above-mentioned variables. This gives rise to what is shown in Figure 4 as a cube. The cube is further broken into smaller cubes that represent specific intersections between CE and SSH.

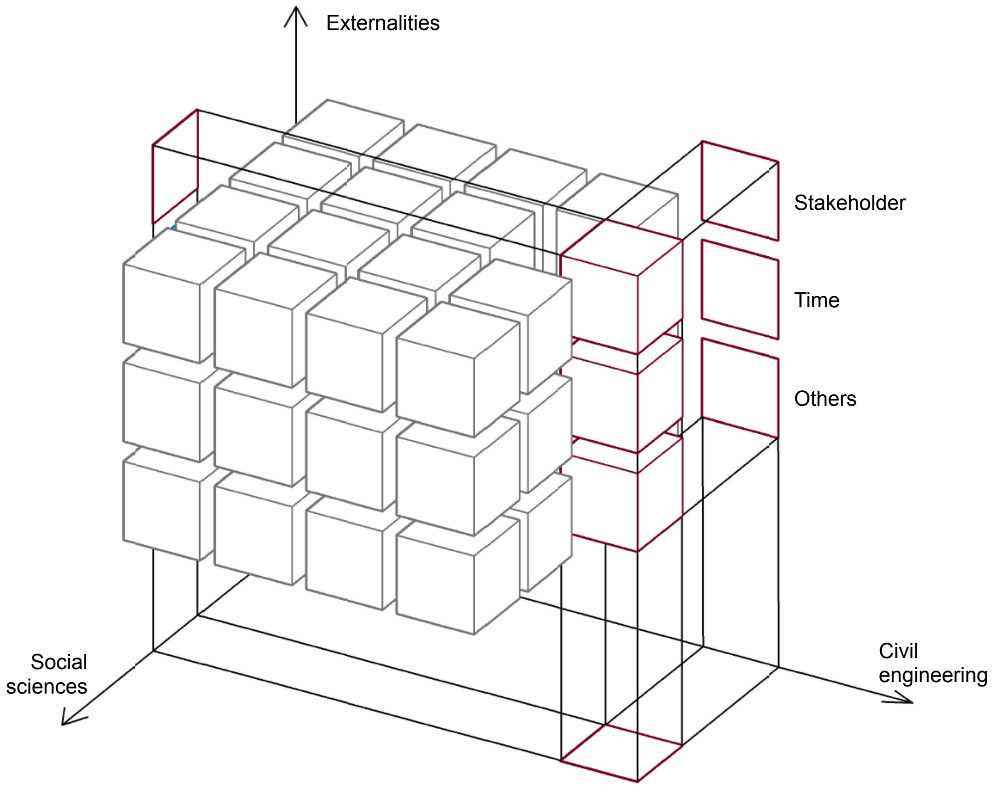

Figure 4 Representation of the relationship between CE and SSH

4.1. Description of specific relationships

This subsection aims at describing the factors concerning the duality of the relationship between infrastructures and SSH. From the performed review, it has been possible to identify and classify all the intersection points between CE and SSH. They are illustrated in Figure 5. This figure shows the duality of the relationships, as well as the topics through which CE and SSH are connected, grouped in different categories.

However, it must be emphasised that current literature does not cover all the relationships that are shown in Figure 5. Namely, there exist research gaps in some of the connections between CE and SSH. For instance, even though we have detected that social aspects can influence the construction of tangible culture, no publication has been found with this regard. In order to better visualise this information. the specific relationships that have been found in the literature are shown in Table A.1. For each of the relationships that have been detected, there is information on the directionality of the relationship found in the reviewed publications. Besides, the table presents as well the indicators that have been found in the literature regarding the different relationships. In the cases in which no indicator was found, the corresponding row has been left blank.

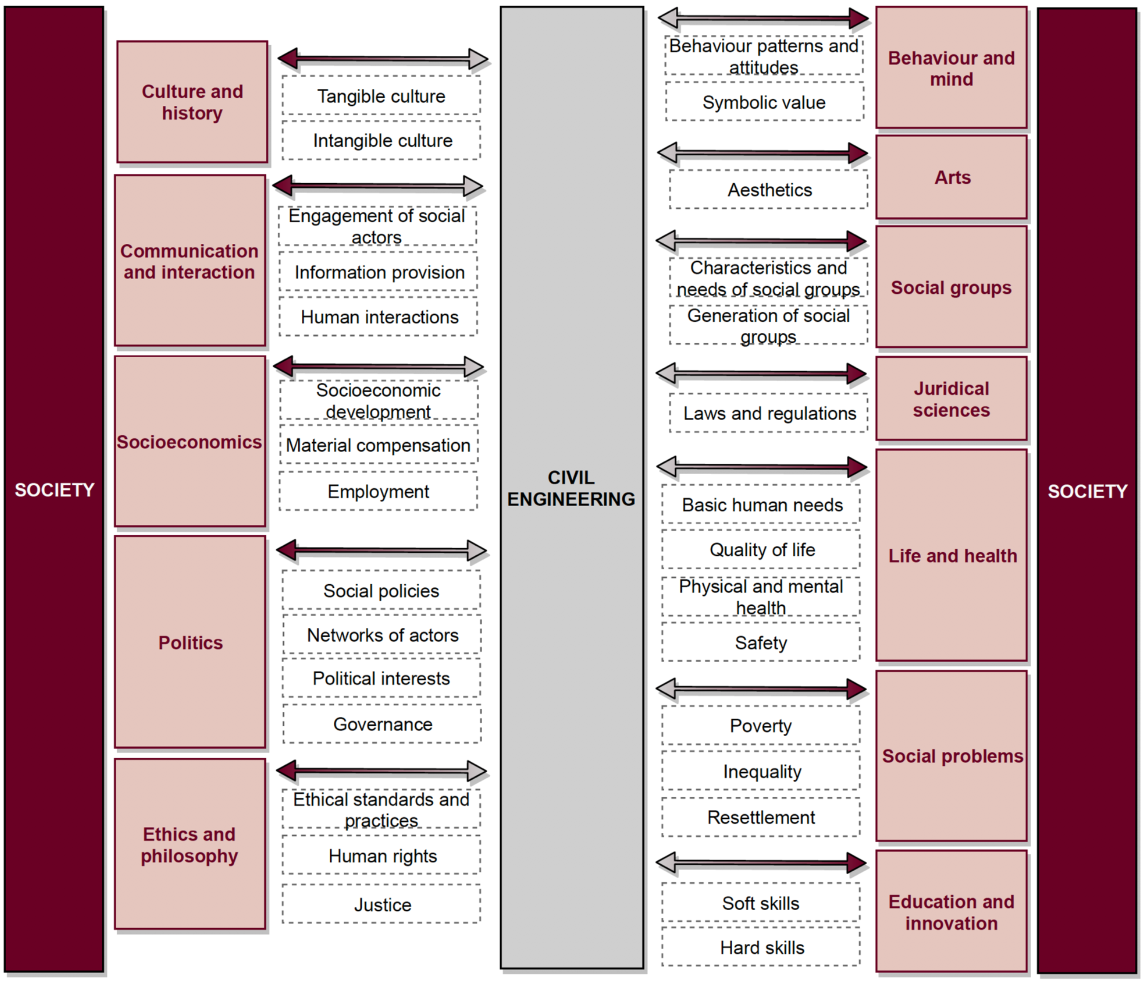

Figure 5 Diagram showing the classification made for each social category

In the following subsections, the relationships shown in Figure 5 are described in more detail.

4.1.1. Culture and history

The social factors associated with culture and history that have been found in the literature can be classified into two subcategories: tangible and intangible culture. First of all, as for tangible culture, urban nuclei or, in general, any human construction, are places where human culture reaches its maximum level of concentration. Infrastructures tangibly represent expressions of human culture and allow to materially preserve aspects such as diversity, habits and values, human aptitudes or interests. As such, any CE work functions both as a driver and as a generator of culture. This aspect includes cultural heritage buildings; even though these structures have usually attracted more attention in the field of culture, tangible culture is not limited to them.

Secondly, these palpable representations of culture are at the same time shaped by intangible culture. This includes cultural characteristics such as customs, traditions, values, norms, attitudes, etc. that may mould the behaviour of human social groups and that are passed down from generation to generation. For instance, these groups can be tribes, ethnic groups or local communities. These characteristics have an effect on the way certain individuals and collectives make use of infrastructures; hence, will have different effects on their demand and use, which is, therefore, a factor to consider in the design and planning of CE works.

4.1.2. Behaviour and mind

One aspect that has been considered in the literature in the dimension of behaviour and mind are behaviour patterns and attitudes. Individual and collective behaviour patterns and attitudes have an impact on the demand and use of infrastructures. This makes it necessary to carry out the design phase according to these needs and characteristics in order to make infrastructures as adequate as possible to their context. Once the structure has been built, it can generate new behaviour patterns that did not exist previously, such as the way individuals travel, consume, spend their free time, etc.

Besides, some authors have also emphasised the symbolic value of infrastructures: CE works can generate feelings of belonging or of local identity, as well as can change how individuals experience and sense places.

4.1.3. Social communications and interactions

As for social communications and interactions, three main areas are the ones that can be found in publications: the engagement of social actors, the provision of information and human interactions.

First of all, the engagement of different stakeholders in the different stages of the lifecycle of the structure includes both the direct participation and the consultation of social actors, such as citizens or citizens organisations and expert committees. Taking into consideration the opinions and knowledge of these stakeholders can result first of all in better-informed decisions; also, it can also benefit the general acceptance of the project.

Secondly, another factor that is englobed in the relationships between stakeholders and that may also favour the project's acceptance concerns the flow of information existing between the civil engineers in charge of the project and the future users and the local community that are affected during the different processes.

Finally, infrastructures have effects on the spatial mobility of people. This impact on spatial mobility and social interactions should always be globally positive or, at least, neutral. However, even though in some cases mobility and the ease of social interaction are positively modified, restriction of physical displacement of people and their interactions can occur as a consequence of infrastructure development too.

4.1.4. Socioeconomics

As an effect of CE works, it is possible that there is socioeconomic development at different levels (local, regional, national, global). This factor has been considered in several of the reviewed references. Among these, one that is usually emphasised is the generation or destruction of employment positions, both in the short and the long term, due to the development of infrastructure projects. Additionally, an aspect that falls into this category is the need for economic compensation to individuals or collectives due to consequences from construction projects.

4.1.5. Juridical sciences

Projects are always bounded by laws and regulations at several different areas such as the relationship between employer and employees (contract procurement, contract conditions, professional conduct, dispute resolution) or the design of the project itself (building codes). Even though they usually have a major effect during the design and planning phase. Actually, special projects or new technologies (such as new materials) introduce new scenarios that maybe weren't contemplated before, which leads to the need for developing new juridical frameworks accordingly.

4.1.6. Life and health

The enhancement of people's life and health is one of the social aspects for which there is generally more agreement on. In this paper, we decompose this factor into four different areas: quality of life, physical and mental health, safety and basic human needs.

The impact that infrastructures can have on society is huge. This impact can either be positive or negative and therefore affected stakeholders can go through an enhancement or a worsening of their quality of life, health and basic needs coverage due to infrastructures. Besides, the consideration of occupational and workplace safety and health are crucial in CE, since civil engineers work in potentially dangerous conditions; at the same time, civil engineers work to design and construct projects that are to accommodate large amounts of people and therefore, a failure in their design can have serious concerns for the surrounding population.

4.1.7. Politics

Three main areas that have been identified in this dimension are social policies, political interests and networks of actors.

First of all, social policies should aim at protecting these rights, as well as enhancing the quality of life of all society in general. Besides, these policies should attempt to develop infrastructure that is both resilient and sustainable. Sometimes, political interests might influence what project is chosen or how it is designed, which can have effects on the performance of these projects. These political interests might be linked to the development of social policies that establish guidelines as for what and how infrastructure projects are developed. Existing literature has also dealt often with the generation of networks of actors as a result of the different stages of the lifecycle of the infrastructure, and how they are involved in the project and what their weight in the final decision is.

4.1.8. Ethics and philosophy

Ethics has been considered by many as a cornerstone for CE professionals. There exist regional codes of ethics that have been developed with the aim of serving as a model for professional conducts. For example, the code of ethics of the American Society of Civil Engineers advocates the "integrity, honour and dignity" in the profession and establishes a collection of fundamental canons to be practised such as the continuation of professional development or a human treatment that is fair and equal. Apart from standards applied to the profession, also aspects of justice and human rights need to be considered in the development of projects, since infrastructures can put key human rights at risk; examples of this are the forced resettlement of communities or threats to life and livelihoods due to the use of land or other resources that local communities were dependant on.

4.1.9. Arts

Visual arts, contrary to what was considered a decade ago, not only includes fine art like painting and sculpture, but also anything that has an expressive component that is mainly visual. Built environments generate a visual impact on their surroundings and they create emotional responses in individuals' minds, which can be positive (attraction), negative (rejection) or even neutral. Additionally, there is a clear aesthetic element in the design process of any infrastructure that is influenced by factors such as the designers' art sensitivities or current artistic movements (like Art Deco, Art Nouveau and Bauhaus). During the operation of the infrastructure, generally no significant modifications are made to it; nevertheless, other art forms such as street art might alter its appearance.

The aesthetic component of infrastructures is predominantly dynamic. Through the perceptions of individuals across generations, the attitudes towards a built work change. There are, also, buildings whose material characteristics and design or whose context (such as climatic) are such that their appearance changes over time; this, also, adds up to the dynamism of its aesthetics. An example of this is the Guggenheim Museum in Bilbao (Spain).

Finally, apart from visual arts, there have been attempts at developing infrastructures with an audio-visual impact instead of visual solely. These infrastructures are scarce in the present.

4.1.10. Social groups

Civil engineers need to consider the particularities and necessities of different social groups, which will affect the demand of the infrastructures they are designing. These groups are defined by varied characteristics: gender, age, socioeconomic class, location, etc.

At the same time, engineers also need to realise that their projects will somehow have an impact on how these groups interact between them, leading to a possible generation (or destruction) of certain social groups.

4.1.11. Social problems

This category is a dynamic one in the sense that as society evolves and CE develops new methodologies and infrastructure types, new social problems might arise, as well as existing social problems can be more easily avoided. From the performed review we have identified two main areas: the resettlement of people and poverty and inequality. As for the last one, there is a clear relationship between poverty and inequality and infrastructures that this has been widely analysed in the literature.

4.1.12. Education and innovation

Two main aspects have been identified regarding education and innovation. First of all, practitioners from all fields need to develop soft skills due to the fact that for better integration between SSH and CE it is essential that both academicians and practitioners work in multidisciplinary fields and are able to effectively communicate ideas to non-experts. These skills include cultural awareness, communication and teamwork. Secondly, it is also necessary to consider the hard skills that are needed in order to adequately integrate CE in a comprehensive social framework (and vice versa).

Differently to the previous social dimensions, education and innovation have additionally driver functions, since they bridge and transmit the knowledge between SSH and CE.

The great majority of publications found dealing with the relationship of education with CE did so in general terms and did not consider the subcategories defined for infrastructures (Bowman and Farr 2000, Russell and Stouffer 2005, Becerik-Gerber 2011, Bacon et al. 2011, Bhandari et al. 2011, Passow 2012, Watson et al. 2013, Lozano and Lozano 2014 and Grigg 2018), except for a small group of publications which mainly dealt with environmental engineering in relation with sustainability (Stokes et al. 1995, Henze et al. 2004, Taylor et al. 2007, Dimitrova 2014, Kováč and Vitková 2015, Panero et al. 2018 and Schmidt et al. 2018).

4.2. Use of the framework

All the concepts presented with regard to the relation existing between infrastructures and SSH can be used as the basis for further work at different levels. The diagram shown in Figure 4 can be seen from different perspectives from which various ways of analysing the relationship stem. These have been illustrated in Figure 6. One can both analyse specific relationships between fields and subfields of both CE and SSH and transversal relations that concern either all the social fields or all the infrastructures fields. For example, governance and inequality are social topics that can be studied transversally, since it concerns all the fields in CE. When analysing specific relationships, it is possible to carry out the analysis globally (considering all the lifecycle stages and all the stakeholders) or more particularly by examining only one or few stages and involved actors.

The classification established, together with the conceptual framework described, can be useful for both practitioners and academics. On the one hand, practitioners can use the concepts developed to structure criteria in decision-making processes, as well as to quantitatively and qualitatively evaluate impacts from CE projects and carry out thorough Life Cycle Analyses. On the other hand, in the academic field, it can be used as a guideline for the structuration of syllabuses of CE higher level education; this can be implemented in specific subjects, or it can be incorporated transversally throughout all the academic years in all the subjects.

Additionally, the performed review can be used by researchers to study specific relationships that have not yet been deeply investigated.

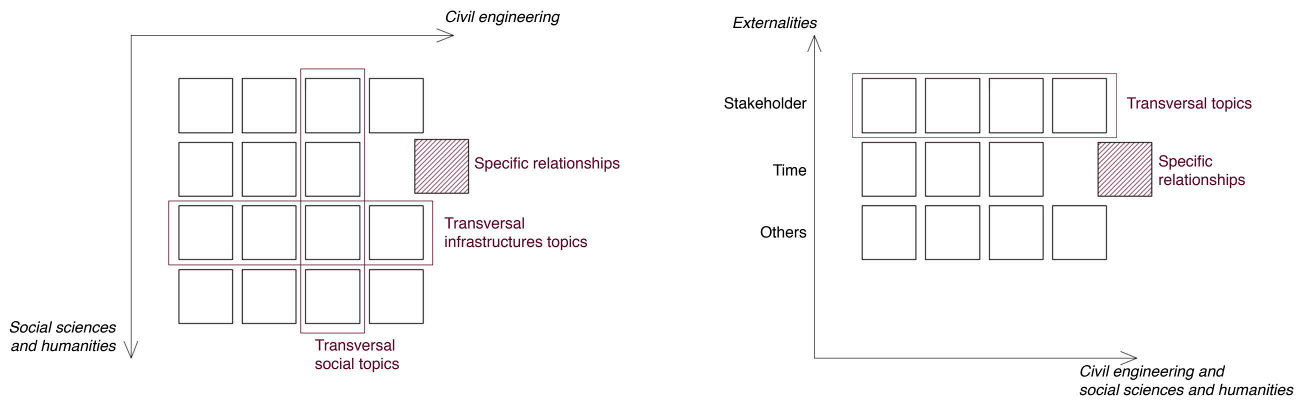

Figure 6 Top view (left) and front view (right) of the diagram in Figure 4

5. Conclusions

In this paper, we discuss the relationship between SSH and CE from a holistic point of view and propose a conceptual framework. We carry out a thorough and systematic literature review of the literature in the intersection between the two fields. In order to do so, we define subfields of CE and of SSH and establish a taxonomy for each of them. Based on the review, first of all, we check that the subdomains for each of the scientific fields that were established encompass all the existing concepts in the literature. Secondly, the review allows establishing a framework that describes both qualitatively and quantitatively the relationships between the scientific fields.

The relationship between CE and SSH can be represented three-dimensionally by considering the externalities that characterise the specific intersections between subfields. These factors are: the stakeholder from whose point of view the relationship is analysed (user, local community, society, worker, etc.); time, which is usually defined through the different stages of the lifecycle of the infrastructure (design and planning, construction, operation and maintenance or decommission); and other possible externalities.

Besides, the relationship is dual, heterogeneous and dynamic. First, the duality is given by the fact that infrastructures both shape and are shaped by social processes; secondly, it is heterogeneous because the strength of the relationship is not the same in all the intersection points; thirdly, it is dynamic because it changes affected by factors such as time.

Not all the specific relationships have been studied at the same level. Social topics such as governance, justice and vulnerability have been most widely studied in relation to CE; as for infrastructures, the field that presents the greatest amount of research on social topics is transport. When it comes to education, much of the research done until the present in the intersection between SSH and CE has focused mainly on the inclusion of concepts related to sustainable development in curricula and lifelong learning programs.

This study can be considered as being the first step towards a better understanding of the connections between two fields that are frequently treated as independent, in spite of the fact that they are actually dependent one on the other. An integrated and interdisciplinary approach to the intersection between CE and SSH is fundamental, both for academicians and for practitioners.

Future studies should aim at taking a closer look at those intersections between CE and SSH that have not yet been studied in depth.

Appendix 1

This appendix describes the middle step performed before obtaining the final set of references analysed in the present article. The keywords used for the search of publications are shown in Table A.1, and the amount of publications found at each search is displayed in Figure A.1. In this figure, a total of 12 colourmap diagrams can be used to identify what combinations of keywords resulted in the greatest amount of publications. Each diagram's colour depends on the number of publications found for a specific social science keyword (horizontal axis) and a specific field of CE (vertical axis).

Table A.1 Keywords used for the literature search in the field of SSH

SSH dimension	*Keywords used*
Culture and history	Culture (1), history (2), ethnics (3), religion (4), symbolism (5), tradition (6)
Behaviour and perception	Behaviour (1), mind (2), psychology (3), emotion (4), personality (5), social perception (6)
Communication and interaction	Social communications (1), social interactions (2), participation (3), information provision (4)
Socioeconomics	Economics (1), economic activity (2), economic development (3), economic geography (4), socioeconomics (5)
Juridical sciences	Law (1), regulations (2), national law (3), legislation (4), tribunals (5), jurisprudence (6)
Life and health	Quality of life (1), well-being (2), mental health (3), physical health (4), life course (5), safety (6)
Politics and policy making	Politics (1), policy making (2), resilience (3), governance (4), social policies (5), public administration (6)
Social problems	Social development (1), poverty (2), inequality (3), social conflict (4)
Social groups	Social groups (1), tribes (2), women (3), children (4), youth (5), elder (6)
Ethics and philosophy	Ethics (1), social philosophy (2), moral (3), justice (4)
Arts	Architecture (1), arts (2), visual appearance (3), aesthetics (4)
Education and innovation	Education (1), educational methods (2), training (3), pedagogy (4), innovation (5)

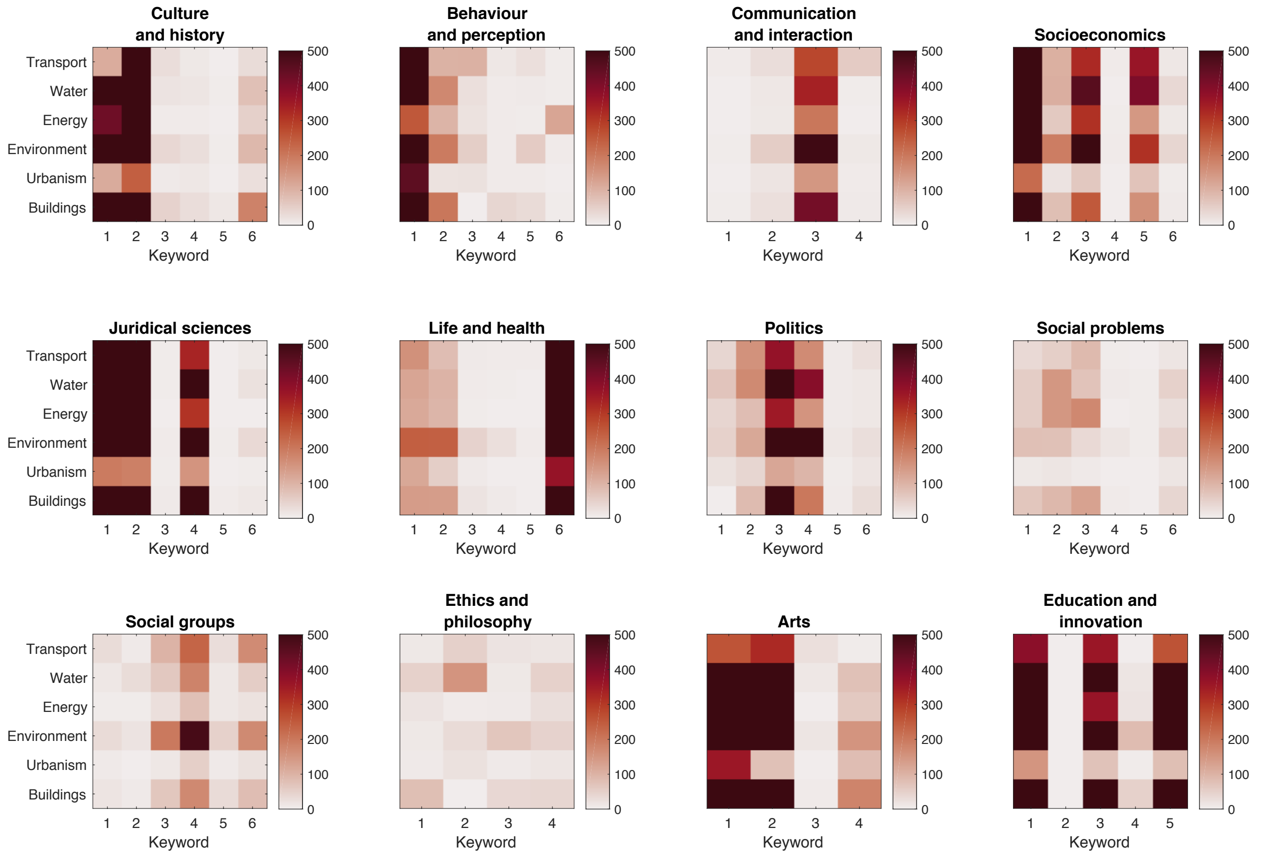

Figure A.1 Number of publications found in the first database search

Appendix 2

Table A.2 gives an overview of whether publications have been found for each of the subcategories established for SSH. For each of these subcategories, the table shows if both directions of the relationship have been studied. Besides, given the fact that indicators can prove useful for analyses of specific areas, those indicators that have been proposed regarding one of the subcategories have also been included in the table. In those cases for which no indicator has been found among the reviewed publications, this has been represented with a dash.

Table A.2 Areas in which references have been found for each of the social subdimensions and corresponding found indicators (if any)

Social subfields	Relationships with CE	Publications found		Proposed indicators (if any)
		From SSH to CE	From CE to SSH	
Culture and history	Intangible culture	✓	✗	Religious values (Ahmadvand et al. 2011, Karami et al. 2017)
	Tangible culture	✗	✓	Historical remains (Axelsson et al. 2013), social and cultural impact due to the project (Koo et al. 2009), Preservation of historical and archeological assets (Koo et al. 2009)
Behaviour and mind	Behaviour patterns and attitudes	✓	✓	Attitude of reference group (Ahmadvand et al. 2011), public support to the project (Koo et al. 2009), social agreement (Pujadas et al. 2017)
	Symbolic value	✗	✓	–
Communication and interaction	Engagement of social actors	✓	✗	Level of participation (Ahmadvand et al. 2011)
	Information provision	✗	✓	Acess to sources of information (Karami et al. 2017)

	Human interactions	✗	✓	–
Socioeconomics	Material compensation	✓	✗	Costs for any relocation (Koo et al. 2009)
	Employment	✗	✓	Local unemployment rate (Sierra et al. 2017), regional history of contracts by project type (Sierra et al. 2017), job creation (Pardo et al. 2019)
	Socioeconomic development	✗	✓	Economic impacts (Litman 2017)
Juridical sciences	Laws and regulations		✗	–
Life and health	Quality of life	✗	✓	Quality of life (Ahmadvand et al. 2011), noise pollution (de la Fuente 2017), interior comfort, hydrothermal comfort (Pons 2018)
	Physical and mental health	✗	✓	Acess to health facilities (Labuschagne and Brent 2008)
	Safety	✓	✓	Insurance costs, prevention costs (Pellicer et al. 2014), occupational risks (de la Fuente 2016), risks during handling (de la Fuente 2017), risk of accident (de la Fuente 2015)
	Basic human needs	✓	✓	Availability of water services, availability of energy services, availability of waste services (Labuschagne and Brent 2006)
Politics	Governance	✓	✓	–
	Social policies	✓	✓	–
	Networks of actors	✗	✓	–

	Political interests	✓	✗	–
Ethics and philosophy	Ethical standards and practices	✓	✓	–
	Human rights	✗	✓	–
	Justice	✗	✓	–
Arts	Aesthetics	✓	✓	Level of perceived acceptability (Labuschagne and Brent 2006), visual comfort (Pons 2018)
Social groups	Characteristics and needs of social groups	✓	✓	–
	Generation of social groups	✗	✓	–
Social problems	Inequality	✓	✓	Neighbourhood characteristics (Wasfi et al. 2017), Gini index (Xia et al. 2016), social risk (Climent-Gil et al. 2018)
	Poverty	✗	✓	–
	Resettlement	✗	✓	–
Education and innovation	Soft skills	✓	✗	–
	Hard skills	✓	✗	–

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